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MINERAL FIBER OBTAINED USING LOW-TEMPERATURE PLASMA

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The properties of basalt fiber obtained using low-temperature plasma are investigated. Basalt wool possesses good physical-mechanical properties. Its chemical stability depends on the composition of the initial raw material. Surfaces with temperature to 500°C can be insulated using mineral wool made from basalt obtained from the Vasil'evskoe deposit and to 700°C for basalt from the Suduntuiskoe deposit.

Key words: mineral wool, basalts, low-temperature plasma.

Energy-conservation efficiency is now a critical question. This has increased demand for heat-insulation materials, specifically, rock wool. Materials based on this wool are used for heat-insulation of the protective walling of buildings and structures, warming interior walls and floors in buildings and heat-insulation of heat supply networks and equipment.

Basalts are one of the main forms of raw material for rock wool. The quality of the basalt fiber obtained depends not only on the chemical composition of the raw material but also on the method used to obtain it. The main units used for obtaining mineral fiber are mineral-wool cupola furnaces and tank, electric-arc and induction furnaces, which are expensive to operate. Plasma setups are most energy-efficient. The specific energy consumption is less than 1 kW · h/kg melt, which is 5 – 10 times lower than in obtaining heat-insulation fiber materials using all known conventional technologies in Russia and abroad. The use of electric-arc plasma to melt basaltic rock lowers the emissions of underoxidized components, because the heating occurs in the interior of the melt. The melt is formed in 15 – 20 min after voltage is applied on the electrodes and the electric-arc plasma is ignited. As the melt fills the working volume the furnace is placed into a stable operating regime [1, 2].

Mineral wool from basalts obtained from different deposits has been obtained using low-temperature plasma and its properties studied [3]. A complex method, including chemical, x-ray phase and microscopic analyses and thermodynamic studies, was used for this. The content of the chemical elements was determined with a SOLAAR atomic-absorption spectrophotometer with the appropriate software. X-ray phase analysis was performed with a D8 Advance powder automatic diffractometer from the Brukeraks Company with the appropriate software and protractor speed 2 °/min in the range from 5 to 70°. The measurement regime for the x-ray diffraction patterns remained constant for all samples. Reference data were used for interpretation. A JEOL JSM-6510LV scanning electron microscope with an INCA Energy 350 microanalysis system from Oxford Instruments was used for microscopic analysis.

Basalt from the Vasil'evskoe (Kemerovo Oblast') and Suduntuiskoe (Zabaikal'skii Krai) deposits were used as raw materials. The chemical composition of these basalts is presented in Table 1.

It was determined from the x-ray phase analysis that the basalts from both deposits consist of the minerals labradorite,

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TABLE 1. Content of the Main Oxides in Basalts

Deposit	SiO_2	Al_2O_3	MgO	CaO	TiO_2	$FeO + Fe_2O_3$	$Na_2O + K_2O$
Vasil'evskoe	53.00	13.50	4.97	9.04	1.10	10.36	3.20
Suduntuiskoe	47.00	18.90	6.06	8.46	1.97	9.52	6.13

TABLE 2. Main Indices of Basalt Wool

Index	GOST 4660–93 specifications	Wool from basalts from the deposits	
		Vasil'evskoe	Suduntuiskoe
Water resistance pH, at most	4	2.22	2.18
Average fiber diameter, μm, at most	6	6.49	8.00
Content of nonfibrous inclusions > 0.25 mm, wt.%, at most	12	5.46	10.21
Density, kg/m^3, at most	80	94.22	153.71
Thermal conductivity, W/(m · K) at $T = 298 \pm 5$ K, at most	0.045	0.038	0.041
Moisture content, wt.%, at most	1	0.29	0.27
Content of organic substances, wt.%, at most	2	0.00	0.00

anortite and olivine. The basalts from the Suduntuiskoe deposit also contain augite.

The initial $t_{ini.m}$ and final $t_{f.m}$ melting temperatures of the basalt were determined in order to make a preliminary assessment of the raw material as well as the type of fiber obtainable from it. These temperatures were $t_{ini.m} = 1100°C$ and $t_{f.m} = 1500°C$. The acidity modulus was calculated with respect to oxides (mass fraction, %) using the relation $M_a = (SiO_2 + Al_2O_3)/(CaO + MgO)$. According to the chemical analysis the acidity modulus equals 4.75 for the Vasil'evskoe basalt and 4.54 for the Suduntuiskoe basalt, which is to be used for superthin fibers.

Microscopic analysis of the mineral wool showed that its constituent fibers are nonuniform with respect to shape and size. Very small quantities of nonfibrous inclusions are present in it. The average diameter of the fibers was determined from the results of the analysis: 6.494 μm for the Vasil'evskoe and 7.998 μm for the Suduntuiskoe basalts.

The types and forms of the basalt wool obtained were determined following GOST 4660–93 'Mineral Wool. Technical Conditions'. The wool obtained is of the VM type — mineral wool with fiber diameter from 6 to 12 μm — and A 3/4 type with acidity modulus above 1.6. It must conform to the current standard. Accordingly, the properties of basalt wool obtained using low-temperature plasma were studied. The results are presented in Table 2.

According to the data in tables the basalt wool obtained does not conform to the GOST standards, but it can be used as a heat-insulation material.

One of the main characteristics of heat-insulation materials is the thermal conductivity, which was determined according to GOST 7076 'Construction Materials and Articles: Method for Determining the Thermal Conductivity and Thermal Resistance in a Stationary Thermal Regime' with the aid of an ITP-MG electronic meter. The thermal conductivity was 0.038 W/(m · K) for the Vasil'evskoe basalt and 0.041 W/(m · K) for the Suduntuiskoe basalt.

The basalt wool and the articles made from it possess high heat resistance. It is stated in all advertisements that it can be used at temperatures to 700°C. A method for determining the maximum application temperature of the wool is proposed in the literature. The crux of this method is a determination of the maximum temperature at which the thickness of the sample decreases by 10% [4].

Samples of basalt wool from fiber obtained using low-temperature plasma were chosen for the present investigations. The treatment temperature was varied from 100 to 700°C. The samples were placed in a furnace with initial temperature 20°C. The temperature was slowly raised to the prescribed value and the samples were soaked in the chamber at this temperature for 4 h, after which the shrinkage and mass loss were measured. The temperature dependence of the shrinkage and mass loss of the basalt wool is presented in Table 3.

It is evident from the data presented that the shrinkage and mass loss of fiber depend on the raw material used. These indices are higher in fiber from Vasil'evskoe basalt. The mass loss resulting from heat treatment is associated with de-watering: free water at 100 – 300°C; interlayer water at 300 – 500°C; and, chemically bound water at 600 – 700°C.

The structure of fibers heat-treated at temperatures to 500°C for Vasil'evskoe and 700°C for Suduntuiskoe basalts remains practically unchanged and comprises a glassy phase with aluminum-silicate composition. Decrystallization of the material starts at higher temperatures. Oxidation of Fe^{2+} to Fe^{3+} occurs as a result of the action of oxygen in air. The material obtained after heat-treatment at 500°C (Vasil'evskoe deposit) and 700°C (Suduntuiskoe deposit) comprises not wool but basalt board. The color of the fibers changes from

TABLE 3. Temperature Dependence of the Linear Indices of Basalt Fiber

Index	Treatment temperature, °C						
	100	200	300	400	500	600	700
Basalt fiber from the Vasil'evskoe deposit							
Shrinkage, %	0.62	0.98	1.72	9.09	22.73	28.18	72.72
Mass loss, %	0.21	0.31	0.45	0.58	0.64	0.66	0.73
Basalt fiber from the Suduntuiskoe deposit							
Shrinkage, %	0.98	1.37	2.11	2.94	3.61	5.45	20.84
Mass loss, %	0.19	0.19	0.20	0.21	0.22	0.22	0.33

TABLE 4. Chemical Stability of Basalt Wool

Deposit	Value of index after treatment in medium					
	H_2O		2N HCl		2N NaOH	
	Δm, g	χ, %	Δm, g	χ, %	Δm, g	χ, %
Suduntuiskoe	0.037	99.20	1.616	53.32	0.549	84.77
Vasil'evskoe	0.027	97.05	0.4149	50.78	0.113	83.33

gray to yellow-brown, which attests to crystallization of the iron-containing phases. The decrease in thickness of a wool sample is 9.09% for Vasil'evskoe basalt at 400°C, and above 500°C it increases sharply to 72.72% at 700°C. For fiber made of Suduntuiskoe basalt this process occurs at higher temperatures. Intense crystallization of fiber is associated with a decrease of volume of the material, which increases fiber brittleness and promotes loss of fiber elasticity and strength. For this reason, the wool obtained using low-temperature plasma can be used to 500°C for Vasil'evskoe and 700°C for Suduntuiskoe basalts.

To determine the physical-chemical properties of basalt fibers it is necessary to study their resistance to aggressive media. In order to use rocks to obtain fibers for different purposes it is necessary, first and foremost, to study the effect of their chemical composition on resistance to acid and alkali. The weak acid resistance of some basalt fibers makes it possible to easily leach them and on this basis to develop high-temperature materials and adsorbents. Acid-resistant basalt fibers can be used as reinforcing materials in the production of fiberglass with special properties. For this reason the study of the effect of individual oxides on the resistance of basalt fibers to external media is of great practical value for choosing the composition of the raw material.

Fibers obtained from Vasil'evskoe and Suduntuiskoe basalts were tested in aggressive media on three samples. Weighed amounts were boiled for 3 h in 250 ml of the corresponding reagent in a flask connected with a backflow condenser [5]. Next the fibers were transported onto a filter, washed with distilled water and dried to constant mass at 110°C after which the average mass losses were determined. The results obtained are presented in Table 4, where Δm is the average mass loss in g and χ is the fiber mass residue after the appropriate treatment, %.

It is evident from the tabulated dependences that Suduntuiskoe basalt wool is more water resistant than Vasil'evskoe basalt wool.

Fibers fall into three groups with respect to acid resistance: soluble, leaching and relatively stable. All of the fibers studied are leaching. They lost all color when processed with hydrochloric acid. Aside from alkali acids, iron oxides were also washed out, which is in agreement with the data on acid resistance. Fibers obtained from Suduntuiskoe basalt have the highest acid resistance, which can be explained by the chemical composition of the fiber (see Table 1).

Fibers obtained from Vasil'evskoe basalt have the highest alkali and alkaline-earth metal content (21.24%) which lowers the acid resistance and low content of silicon, aluminum and iron oxides content (63.86%) which increases acid resistance. The content of these oxides in Suduntuiskoe basalt fibers is 20.65 and 75.42%, respectively, which is what makes them more acid resistant.

It is evident from the data presented in Table 4 that basalt fibers possess adequate resistance to alkali. The Suduntuiskoe basalt fibers have the highest alkali resistance.

This property makes it possible to use fiber to reinforce asphalt-concrete coatings on roads, concrete structures of bridges, tunnels, dams, concrete covers and elsewhere, i.e., in locations where the effect of moisture, salts and chemically active media results in corrosion of metallic armature. Owing to their chemical stability basaltic fibers are an irreplaceable material to fabricate filters for purifying industrial effluents.

In summary, fiber made from basalts obtained from the Vasil'evskoe and Suduntuiskoe deposits possess good water and alkali resistance and very low acid resistance. Mineral wool obtained from Vasil'eskoe and Suduntuiskoe basalts with aid of low-temperature plasma is GOST 4640–93 compliant with respect to all indices except density and is used as heat-insulation material in construction and industry to insulate surfaces with temperature to 500°C and 700°C, respectively.

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